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INDUSTRIAL WASTE PROCESS DESIGN

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INDUSTRIAL WASTE PROCESS DESIGN

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Donald J. O'Connor,** J. M. ASCE

Synopsis

The economic importance of industrial wastes stresses the necessity of considering the fundamental aspects of waste treatment. The analysis and application of the data derived from the industrial waste survey are presented. The function of laboratory and pilot plant studies to the design of prototype units is discussed. The paper also includes a review of the theory of sedimentation and aerobic biological treatment and the practical application of this theory to the design of processes for specific waste problems. Data has been derived from studies on cannery, pulp and paper, packing house, dairy and paint wastes. Much of the theory is the work of others and is appropriately referenced. The symbols used in this paper are defined in the appendix.

Survey

The first step in industrial waste process design is the waste survey which is conducted to determine the sources, magnitude and variation of pollution within the industrial plant. The duration of the survey is determined by the variability of the particular industrial process.

The frequency of sampling is usually established by the nature of the process, i.e., batch, intermittent or continuous. Individual or short time composite samples on the most important waste characteristics and daily composite samples on all characteristics should be collected for analysis.[1] All composite samples should be weighted according to flow. Oxygen demand, solids, flow and nutritional content are necessary factors to determine the waste treatment design, while characteristics such as pH, temperature, toxic elements, etc. are vital to the design of process control mechanisms. Simplified analytical procedures are desirable for laboratory analysis and control. For example, the C.O.D. test may frequently be substituted for the B.O.D. or volatile solids test provided a significant correlation can be established between the two characteristics.

Waste flow data is frequently available from plant records. In the absence of records or metering devices, it is necessary to install such means which can be accommodated by the physical features of the plant.[2] In batch processes, time and volumetric readings are adequate, whereas in continuous processes, comparable measuring devices are necessary. In order to derive

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Note: Small numbers in text refer to references appearing at end of this paper (pages 411-10 - 411-11).

design criteria, flow measurements should be taken not only on the total waste, but also on the individual sources of waste throughout the plant.

On Figures 1 and 2 are shown flow diagrams of a paint manufacturing process and a fruit canning process, indicating locations where waste samples and flow measurements were taken. The total waste flow and loading is composed of several components which may be balanced as shown in Tables 1 and 2. An analysis of such a flow and material balance frequently indicates an economical solution to the waste treatment problem by eliminating or reducing the quantity of waste matter or waste water. A reduction of this nature can be accomplished by the following methods:

1. Recovery or utilization of waste products.
2. Removal of waste matter in a dry state, i.e. appreciable economic saving was effected by removing the concentrated wastes in a dry state from the canning operation mentioned above.
3. Segregation of non-contaminating waste water. Non-contaminated process water can frequently be removed from the waste system for direct discharge to the receiving body. By such segregation, the hydraulic load to the waste treatment plant may be reduced.
4. Recirculation of waste waters. Some industrial processes do not require a water of high quality and, therefore, could use as supply the waste water from other units in the plant. Recirculation of this nature reduces the hydraulic load and concentrates the waste load.

Analysis of Data

The strength and flow characteristics of most wastes are highly variable and are usually susceptible to statistical analysis.[3] These variations may be caused by production changes in continuous processes, and by random discharges in batch operations. An example of batch operation, its flow pattern and the statistical variation of flow data are shown in Figure 3. Corresponding waste strength data may be analyzed in a similar manner.

Frequently flow variations may be correlated to unit operations and production schedules as shown in Figure 4. In these data, the standard deviation of the flow for any number of units operating was low and, therefore, mean values were employed to evaluate the flow pattern. The total waste flow is composed of several unit flows. Batteries A and B vary directly with the number of units in operation. Other flows, independent of the number of units in operation are shown by the difference in total flow and the battery flows.

Design Criteria

The type of waste treatment to be selected should be based on a consideration of the physical, chemical and biological characteristics of the wastes determined by the survey. Consideration must be taken of the frequency and magnitude of shock loads and of variation of waste loading during industrial operations. In addition to standard methods of treatment, other methods may be employed such as solvent extraction, evaporation, anaerobic digestion and flotation for specific waste problems. Occasionally, it is necessary to consider separate treatments for specific wastes within an industrial process.

Sedimentation

When a significant portion of the waste substrate is present as suspended solids, sedimentation will usually provide an economical method of treatment. The principles involved in sedimentation have been presented an excellent compendium by Camp.[4] The application of these principles in reference to industrial wastes may be employed in laboratory and design procedures.

Theory

Gravity forces are those impelling settling and drag forces are those resisting settling. The drag forces may be classified as inertia, (Newton's Law) and viscosity, (Stoke's Law), the latter being a temperature function. The ratio of these forces is defined by the Reynolds number:

$$R = \frac{dv}{u}$$

When this ratio is high (large particles of comparatively high density), the inertia force is predominant, and when the ratio is low, viscosity is the major force, with temperature an important factor. In many industrial wastes, both inertia and viscosity are significant in the range and nature of suspended solids encountered. When the concentration of suspended solids is sufficiently high, the settling paths of particles interfere and the sedimentation process is hindered. Various investigators have evaluated this hindrance[4,5] from which it has been found that the concentration of waste suspended solids must be less than approximately 1000 ppm to insure free settling.

The settling velocities, computed from the size and density of a particle, pertain to discrete particles of spherical shape. Usually the suspended solids encountered in the wastes are not discrete but are of a flocculent nature. Although subject to the same forces, they are influenced by agglomeration which increases the size and density and changes the shape of the particles. As agglomeration proceeds, the settling rates tend to increase due to particle coalescence. The greater the concentration of suspended solids up to the zone of hindered settling, the greater will be the removal by settling, as is shown in Figure 5. These data are representative samples of a pulp and paper waste.

Laboratory Procedure

For a specific waste, the nature (flocculant or discrete) and the concentration of the suspended solids must be correlated to the settling characteristics (free or hindered) to design the most efficient sedimentation units. In order to obtain the data required for design, laboratory studies should be conducted as described by Camp.[4] This test consists of determining the concentration of suspended particles in a quiescent settling cylinder at various depths and at various time intervals. These tests are performed under ideal conditions, and, therefore, give ideal removals which cannot be fully realized in a prototype settling tank. The necessary design data on settling velocities and detention times for any suspension may be evaluated.[6] The efficiency of the process is reduced by turbulence,[7] short circuiting and temperature and density currents,[8] and is increased by greater flocculation, due to velocity gradients.[9]

Design Application

An example of the variation in concentration and nature of the suspended solids, caused by changes in an industrial process, is shown by the following data on a pulp and paper waste. The suspended solids in the raw waste "A", with low lime content, is about 500 ppm, while waste "B" with high lime content, averaged about 2000 ppm. The settling characteristics of these suspensions are shown in Figure 6. The lime waste exhibits the much greater subsidence rates. The relations indicated are based on the concentration readings at 2 feet and 6 feet depths for various time intervals. From the depth and time data, settling velocities can be computed for concentrations, expressed as a ratio to the initial concentration. Assuming a design settling rate of 5.5 ft. per hour, which is equivalent to an overflow rate of 1000 gal. per day per ft.,^{2} 96% of the suspended solids of the lime waste have settling rates greater than 5.5 ft. per hour as compared to 60 - 65% of the suspended solids of the waste without lime.

The two curves for waste "A" point out the influence of flocculation on those particles which have the higher settling rates. For example, 33% of the suspension for the 2 ft. data has a settling velocity equal to or greater than 12 ft. per hour, while the 6 ft. readings show 60% of the suspension has a settling velocity equal to or greater than 12 ft. per hour. The time required to settle 2 ft. was 10 minutes and to settle 6 ft., 30 minutes. Therefore, the additional time to settle the 4 ft. increased the settling efficiency by 37%. The effect that time has on efficiency of removal is shown in Figure 7. For a given efficiency of removal, the overflow rate will increase proportionally to an increase in detention time if flocculation effect is apparent. For example, in Figure 6, to obtain at least 60% removal, the two foot curve indicates an overflow rate of 1000 gal. per sq. ft. per day and a theoretical detention time of 20 minutes while the six foot curve indicates an overflow rate of 2200 gallons per sq. ft. per day and a theoretical detention time of 30 minutes. With the particles of lower settling velocity, the effects of flocculation are less pronounced as is evidenced by the joining of the two curves in Figure 6. When flocculation is not occurring, efficiency of removal is independent of time. From a plot such as Figure 6, the settling rate and the detention time can be determined for any required removal. The actual detention time can be approximated by taking into account the short circuiting characteristics.[10] In an existing tank, the short circuiting effects can be experimentally determined.[11]

The influence that concentration has on settling characteristics is shown in Figure 5, which represents the subsidence velocity curves for various concentrations of raw waste. These plots also indicate the effect that the nature of the waste has on the settling characteristics. The higher concentration waste is a sample of a composite mixture from all processes in an industrial plant, whereas the lower concentration wastes are those from a portion of the plant processes. The range of suspended solids concentration shown are those to be expected for a 10% frequency to a 90% frequency for the waste indicated.

Having data available, as indicated in Figures 5, 6 and 7 economic sedimentation units can be designed and the efficiency of these units can be evaluated for various concentrations of suspended solids and flow rates.

It is advisable in conducting such tests to determine the removal of other pertinent characteristics, such as B.O.D., C.O.D., etc., such that the solids and oxygen demand loading on subsequent units can be estimated.

Although the data previously presented refer to the sedimentation of non-biological suspensions, the same principles and procedures may be employed in determining the settling and compaction characteristics of biological suspensions. The nature of the waste and the process environment establishes the characteristics of the sludge. In this regard, two factors must be considered: the rate of sludge compaction[11] and the rate and nature of its biological decomposition in an anaerobic environment. The latter factor may be estimated employing oxidation reduction potential measurement.[12] For example, an activated sludge from a food processing waste could not be maintained in a final tank for long periods due to its high activity and gas production. As a result, the maximum sludge concentration attainable was 0.4 to 0.7%. By comparison, an activated sludge from a pulp and paper waste could be maintained for extended periods in the final settling tank due to its low activity and non-gas forming properties. Concentrations as high as 3.0% could be attained.

In addition to the above mentioned factors, the ecological characteristics of the suspension must be considered. Improper control of these characteristics may cause decrease in sludge settle ability which has been attributed to insufficient air, excessive filamentous growths, excessive carbohydrates, etc.

The specific gravity of the bacterial mass which has been reported to vary from 1.02 to 1.12 can be directly related to the growth cycle of the organisms and, thus, to the available food. In industrial systems which support several species of microorganisms, the conditions established in the process will tend to repress or stimulate the growth of particular species. For example, in treating pulp and paper wastes by activated sludge, the maintenance of fully aerobic conditions stimulated the growth of filamentous forms of low settling rate. When this sludge was allowed to settle in a clarifier under anaerobic conditions for several hours, these forms were suppressed and the sludge settling rates increased.

Chemical Treatment

As a basic guide for the design of the various units and equipment, a flow and material balance diagram is helpful. Such a diagram indicates the flow pattern of the liquid and solid waste through the treatment process.

In the design of waste systems employing coagulation or chemical treatment, it is usually desirable to balance the process on pertinent waste characteristics such as total, volatile or suspended solids. Stociometric principles may be employed to derive a material balance for average loading conditions and statistical analysis of waste data to indicate the variation about this average.

Coagulant dosages must be experimentally determined for the range of waste concentrations. This procedure was employed in determining the alum dosage required for a paint and pigment waste. The flow diagram for the treatment process is shown on Figure 8 and the material balance is shown in Table 3. Coagulation with alum removed the pigment constituents in the suspended and colloidal state but did not remove the high oxygen demand of the dye constituents. Segregation and separate treatment of these wastes were initiated to afford the most economical solution.

Biological Oxidation

Industrial waste design is complex in biological systems because of the transformations in state and character of the waste substrate during the treatment process. Organic matter in soluble and colloidal form is transformed into gaseous end products and cell structure by biochemical action. The basic equation describing any aerobic biological process is:

$$\text{Organic Matter} + O_2 + NH_3 = \text{Sludge} + CO_2 + H_2O \quad (1)$$

Approximately 60% of the organic matter removed is assimilated to cell tissue (sludge) and 40% is burned to CO_2 and H_2O to obtain energy for this assimilation.[13] In addition to the above reaction, the sludge produced undergoes continuous auto-oxidation.

$$\text{Sludge} + O_2 = CO_2 + H_2O + NH_3 \quad (2)$$

The rate of oxidation of organic matter (Eq. 1) is 10-20 times the rate of auto-oxidation[13] (Eq. 2). Definite stociometric relationships exist depending upon the chemical character of the organic matter to be oxidized, the oxygen and nitrogen utilized in the process, and the quantity of sludge produced by the process. Hoover[14] has formulated these relationships for dairy waste oxidation.

Since the exact chemical characteristics of most wastes are generally not know, the necessary factors to balance the above equations must be obtained by experimental methods either in the laboratory or a pilot plant. A pilot plant will reproduce the conditions which exist in the treatment process and the data derived from the operation may be utilized to provide the necessary design basis for oxygen requirements, sludge production and nutrient requirement as shown by Eq. (1) and (2). These concepts apply to all aerobic biological systems.

Activated Sludge

The determination of the detention time and solids concentrations which must be maintained in the system in order to effect the desired B.O.D. reduction is a primary consideration in the design of an activated sludge system for organic wastes. B.O.D. removal efficiency has been found by several investigators[15,16,17] to be a function of organic loading, activated solids concentration, and the time of aeration. The loading parameter is usually expressed as unit weight B.O.D. per unit weight activated sludge per unit time of contact. Figure 9 shows treatment efficiency data obtained on several industrial wastes. This relationship holds true for most organic wastes providing that sufficient oxygen, nitrogen, etc. is maintained in the system. The required aeration volume can be computed from this relationship to attain a given effluent quality for any loading, time of aeration and mixed liquor solids. The mixed liquor solids and the time of aeration are influenced by the rate of recirculated sludge. The solids which can be maintained are limited by the ability of the system to transfer the requisite quantities of oxygen and the qualities of the sludge with respect to settling and compaction in clarification units. The formulation as shown in Figure 9 in conjunction with the statistical variation of organic loading and flow may be employed to derive an efficiency curve for the system being designed for all anticipated conditions.

It is necessary to supply oxygen to the biological mass at a rate equal to or greater than its rate of utilization in order to insure a consistent degree of treatment efficiency. The rate at which oxygen will be transferred to the liquid sludge mass may be expressed by the formula:[18]

$$r_d = k_g (p-pi) = k_L (pi-pk) - k_c (p^* - pc)$$

In aeration systems, the liquid film resistance will control the rate of oxygen transfer. In order to attain the most effective oxidation, the sludge must be in a dispersed phase through agitation since sludge clumping reduces the rate of oxygen transfer to the cell interface.

It has been found that when the oxygen concentration is greater than 0.5 ppm, the rate of bacterial respiration is independent of oxygen concentration, but below 0.5 ppm, the system becomes oxygen dependent and the rate of oxygen utilization and B.O.D. removal is markedly reduced. Figure 10 illustrates the deterioration in treatment efficiency accruing from insufficient oxygen supply in an activated sludge system treating pulp and paper wastes.

The ultimate B.O.D. of an organic waste represents the oxygen equivalent of that waste. A portion of this oxygen equivalent is directly utilized in the oxidation of organic matter as shown in Eq. 1. This oxygen requirement may be directly computed if the chemical composition of the waste and its biological response is known. In addition to the oxygen required for stabilization of the organic matter, oxygen is also required for the endogenous respiration of the mixed liquor sludge as shown in Eq. 2. This rate will vary from 3-10 ppm per hour for 1000 ppm of activated sludge depending on the length of time the sludge has been undergoing oxidation.[14] The total rate of oxygen utilization is the sum of the endogenous rate and the rate of organic matter oxidation. In an aeration system treating pulp and paper waste of low B.O.D. loading, the average oxygen utilization rate was only 10-15 ppm per hour per 1000 ppm of sludge while in a high B.O.D. food waste oxygen utilization rates as high as 100 ppm per hour per 1000 ppm of activated sludge were found. When the chemical composition of the waste is not known, pilot plant studies may be employed to compute the oxygen requirements. For example, investigation of a food processing waste revealed that 29% of the B.O.D. was directly oxidized and 71% went into the synthesis of new sludge. The gross oxygen requirement of the system would then be computed as the sum of the oxygen required for the organic matter representing 29% of the ultimate oxygen demand and the endogenous respiration of the sludge. This endogenous rate was found to be 14% per day of the mixed liquor volatile solids. The estimation of the anticipated range of oxygen utilization rates which may be expected for various hydraulic and organic loadings may be obtained from a statistical analysis of pilot plant data.[19] The aeration system may be designed directly from these data. The oxygen utilization rate will vary with the loading, detention time and solids concentration. Figure 11 shows the variation in oxygen utilization rate with respect to variation in process loading obtained in the activated sludge treatment of food processing wastes.

The oxygen utilization rates may be computed from the following relationship;

$$\text{lbs. } O_2 \text{ utilized} = X + Y \quad (3)$$

in which X and Y represent the percent of ultimate B.O.D. oxidized and the oxygen required for the endogenous respiration of sludge respectively.

The design of the aeration system should be such that minimum oxygen concentrations are maintained under conditions of maximum loading derived from the frequency analysis.

From equation 1, it is seen that sludge in the form of cell structure will be produced in a biological system proportional to the quantity of organic matter removed by the system. Hoover et al[14] found that dairy wastes treated by activated sludge produced 52% sludge by weight of the organic matter removed. The sludge produced by that system had the empirical formula

$$C_5 H_7 NO_2$$

The composition of most activated sludge approximates this formula and contains 90-93% volatile solids. Volatile solids content less than this will usually be due to the presence of inert substances in the sludge.

Several empirical relationships have been devised to estimate the sludge production from activated sludge systems.[16,20] In most cases, the quantity of sludge produced for disposal will be equal to the quantity of non-biological suspended solids removed in the process plus the quantity of activated sludge produced by synthesis less that portion oxidized by the endogenous respiration of the system.

$$\text{Pounds excess sludge} = S + (1-X) - Y \quad (4)$$

where X represents that portion of the B.O.D. removed which is synthesized, Y the sludge oxidized by the endogenous respiration of the system, and S the pounds of inert suspended solids removed in the system.

From the above formulation, it is seen that the greater the mixed liquor solids concentration, the less the net sludge for disposal.

In order to evaluate equations 3 and 4, it is desirable to express all variables in terms of equivalent oxygen demand. A relationship will usually exist between chemical oxygen demand and the volatile solids content of activated sludges. This relationship for several sludges studied is shown below:

SUBSTANCE	RATIO $\frac{\text{C.O.D.}}{\text{VS}}$
Activated sludge - pulp and paper waste	1.38
" " - domestic sewage	1.44
" " - dairy waste	1.36

The above relationship show that 1 pound of activated volatile solids requires 1.36 - 1.44 pounds of oxygen for its complete oxidation.

Definite quantites of nitrogen and phosphorus are required by a biological system for the removal of organic matter. In many industrial wastes such as those emanating from the food processing industries, the quantity of nitrogen and phosphorus is insufficient for the complete assimilation and oxidation of the carbonaceous substrate. The measure for adequate nitrogen is the maintenance of a minimum content in the sludge produced by the process. The nitrogen content of sludges will vary from 6-14% depending on the characteristics of the sludge mass and on the availability of nitrogen. Sawyer[21] found the minimum nitrogen content to be 7% and the minimum phosphorus content 1.2% of the volatile solids to insure maximum process efficiency.

In any given system, all of the above variables must be balanced such that the net input of organic matter, oxygen, nitrogen and solids is equal to the net output of sludge, gaseous products, nitrogen, etc. The material balance for activated sludge systems may be expressed in terms of equivalent oxygen demand:

lbs. O_2 in = lbs. O_2 effluent + lbs. sludge produced + lbs. oxidized to end products.

To evaluate this balance, it is necessary to compute the C.O.D. or B.O.D. of the waste entering and leaving the system, the quantity of sludge solids produced in terms of C.O.D. or volatile solids and the quantity of oxygen consumed in the system.

A flow diagram and material balance for a typical activated sludge plant treating food processing wastes are shown in Figure 12 and Table 5.

The above material balance establishes the average conditions which may be anticipated in the treatment process.

In industrial systems, components are frequently present which will disrupt the waste treatment process. Among these factors are pH, the presence of heavy metals, phenols, solvents, etc. which must be controlled to insure continuous and efficient operation.

One of the most common factors influencing biological efficiency is pH[22] which is a parameter of enzyme activity. Figure 11 shows the detrimental effect of the pH of a pulp and paper waste on an activated sludge system.

Trickling Filters

The principles discussed above, are equally applicable to the design of trickling filters, but have not been evaluated quantitively to the same extent. It has been shown that the quantity of biological film which consists of cells and organic matter at various stages of decomposition varies directly with the loading and removal of suspended solids and B.O.D.[23] Eq. 1 and 2 express these relationships. Temperature, which is an important factor in the efficiency of a biological system, apparently has a greater influence on the efficiency of a trickling filter than of activated sludge. This may be attributed to the physical relationship of the biological system in a filter to the ambient temperature.

Various methods have been proposed for evaluating the efficiency of a trickling filter which are similar to those employed for activated sludge[24, 25]. These methods have been derived from data on domestic sewages, primarily and a comparison of the efficiencies determined by these methods has been presented.[26]

Conclusions

Industrial waste surveys provide the data on waste loading and flow for process design and control. The frequency of occurrence of these parameters may be evaluated by statistical analysis. Laboratory and pilot plant studies may be employed to evaluate the settling and biological characteristics of wastes. A basic theory for aerobic biological treatment is offered with its application to the treatment of industrial wastes. Design criteria are presented in the form of a process material and flow balance.

APPENDIX

R = Reynolds Number
d = diameter of particle
v = velocity of subsidence
u = absolute viscosity of liquid
k_g = gas film resistance
k_L = liquid film resistance

k_c = liquid-sludge film resistance
p = oxygen partial pressure in the gas phase
pi = oxygen partial pressure at the gas-liquid interface
p_L = oxygen partial pressure in the liquid bu
p* = oxygen partial pressure at the organism interface
p_d = rate of oxygen transfer

REFERENCES

1. Weston, R.F., Merman, R.G., and De Mann, J.G., Industrial Plant Waste Disposal Survey, Sew. Wks., J. 21, 2, 274.
2. Planning and Making Industrial Waste Surveys, Ohio River Valley Water Sanitation Comm., April, 1952.
3. Velz, C.J., Graphical Approach to Statistics, Water and Sew. Wks, April, 1952.
4. Camp, T.R., Sedimentation and the Design of Settling Tanks, Transactions, ASCE, 1946.
5. Kalinske, A.A., Settling Characteristics of Suspensions in Water Treatment Processes, J. American Water Wks. Assoc. 40, 2, 113, February, 1948.
6. Reid, W.P., Use of Tangent Intercept to Determine Average Speed of Sedimentation, Analytical Chemistry, 25, 10, 1562, October, 1953.
7. Dobbins, W.E., Effect of Turbulence on Sedimentation, Trans., ASCE, 109, 2218, 1944.
8. Anderson, N.E., Design of Final Settling Tanks for Activated Sludge, Sew. Wks. J., 17, 1, January, 1945.
9. Camp, T.R. and Stein, P.C., Velocity Gradients and Internal Work in Fluid Motion, J. of Boston Society of Civil Engineers, October, 1943.
10. Camp, T.R., Sedimentation Basin Design, Sew. and Ind. Wastes, 25, 1, January, 1953.
11. Morrill, A.B., Jour. Amer. Water Wks. Assoc., 24, 1442, 1932.
12. Eckenfelder, W.W. and Hood, J.W., Application of Oxidation-Reduction Potential to Biological Waste Treatment Control, 6th Purdue Ind. Waste Conf., Proc., February, 1951.
13. Hoover, S.R., et al, Biochemical Oxidation of Dairy Wastes, Sew. and Ind. Waste 24, 9, Sept. 1952.
14. Hoover, S.R., Biochemical Oxidation of Dairy Wastes, Sew. and Ind. Wastes 25, 2, February, 1953.
15. Fair, G.M. and Thomas, H.A., Jr., The Concept of Interface and Loading in Submerged Aerobic Biological Sewage Treatment Systems, Jour. and Proc. Inst. Sew. Purif., Part 3, 235 (1950).
16. Smith, D.B., Aerobic Biological Stabilization of Organic Substrates, Sew. and Ind. Wastes 24, 9, Sept., 1952.
17. Weston, R.F., (Unpublished data).

18. Hixon, A.W. and Gaden, L.J., Oxygen Transfer in Submerged Fermentation Ind. Eng. Chem. 42, 1792, (1950).

19. Eckenfelder, W.W., Aeration Efficiency and Design, Sew. and Ind. Wastes, 24, 11, Nov., 1952.

20. Heukelekian, H. Orford, H.E. and Manganelli, R., Factors Affecting the Quantity of Sludge Production in the Activated Sludge Process, Sew. and Ind. Wastes, 23, 8, 945, Sept., 1951.

21. Sawyer, C.N. et al, Nutritional Requirements in the Biological Stabilization of Industrial Wastes, Sew. and Ind. Wastes 24, 4, April, 1952.

22. Eckenfelder, W.W., Effects of pH on Biological Treatment, Manhattan College Inst. Conf., May, 1953.

23. Heukelekian, H., Relationship Between Accumulation and Biological Characteristics of Film of a Bio-filter and a Standard Filter, Sew. Wks. J. 17, 1, Jan., 1945.

24. National Research Council, Sewage Treatment at Military Installations, Sew. Wks. J. 18, 5, 791, Sept., 1946.

25. Velz, C.J., Basic Law for Performance of Biological Beds, Sew. Wks, J. 20, 4, July, 1948.

26. Rankin, R.S., Performance of Biofiltration Plants by Three Methods, Proceedings ASCE, 79, 336, November 1953.

MATERIAL AND FLOW BALANCES FOR VARIOUS INDUSTRIAL WASTES AND TREATMENT PROCESSES

TABLE I (Paint Waste Survey)

(See Figure I)

	Waste Source						
	1	2	3	4	5	6	7
Flow, gallons per day	925	1800	9600	295	500	17300	30420
Volatile Solids, lbs. per day	40	48	104	45	27	55	319
Total Solids, lbs. per day	50	266	226	87	62	88	779
Suspended Solids, lbs. per day	4	170	100	27	15	15	331

TABLE II (Canning Waste Survey)

(See Figure II)

	1	2	3	4	5	6	7
Flow, gallons per min.	560	560	150	75	200	1520	
C.O.D., lbs. per day	2210	3710	371	9050	384	15725	
Suspended Solids lbs. per day	870	1570	27	2995	78	5540	

TABLE III (Chemical Treatment)

(See Figure VIII)

	1	2	3	4
Flow, gallons per day	30,000	—	2500	27,500
Total Solids, lbs.	639	85.8	613	112
Volatile Solids, lbs.	278	—	240	38

TABLE IV (Activated Sludge Treatment)

(See Figure XII)

	Raw Waste	Oxygen to Aerator	Waste Sludge	Plant Effluent
Flow, MGD	0.55		0.013	0.537
C.O.D., lbs. per day[1]	3000	1147	1515	338
S.S., lbs. per day	100	—	1225	100

[1] Waste constituents in terms of ultimate equivalent oxygen demand

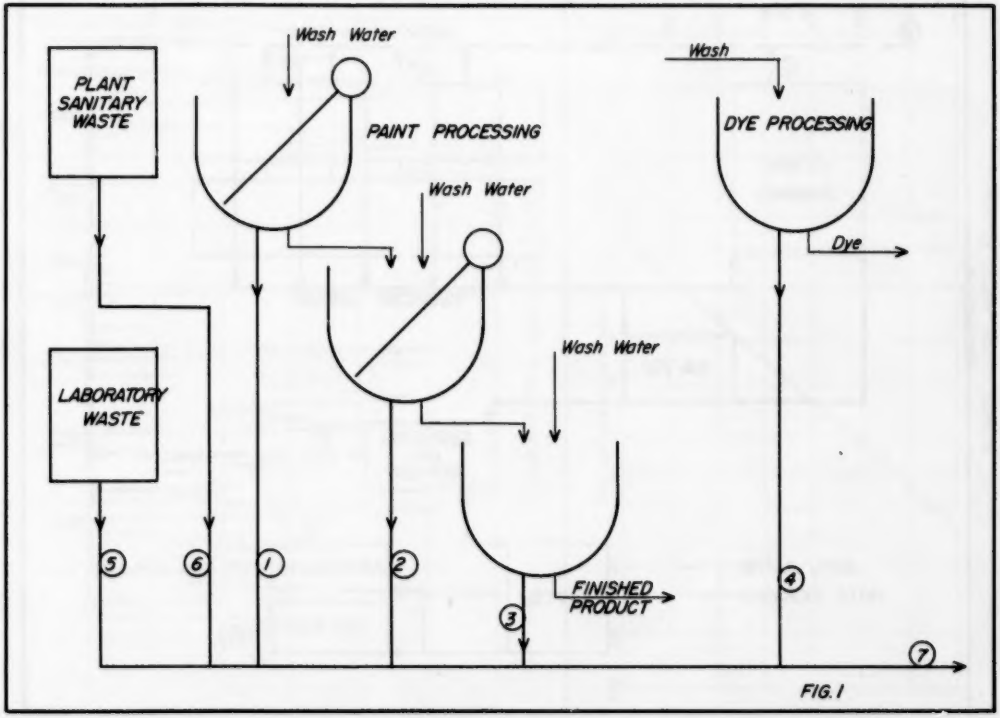
Wash Water
PLANT SANITARY WASTE
PAINT PROCESSING
Wash
DYE PROCESSING
Wash Water
Dye
Wash Water
LABORATORY WASTE
FINISHED PRODUCT
5
6
1
2
3
4
7

FIG. I

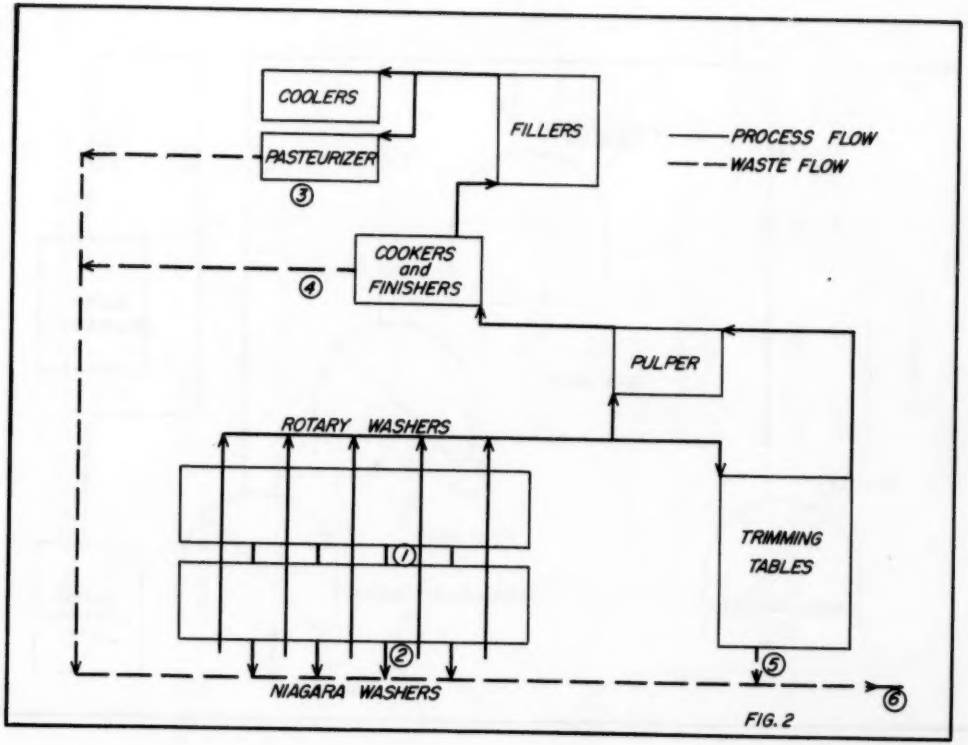
COOLERS
FILLERS
PROCESS FLOW
WASTE FLOW
PASTEURIZER
3
COOKERS and FINISHERS
4
PULPER
ROTARY WASHERS
1
TRIMMING TABLES
2
5
6
NIAGARA WASHERS

FIG. 2

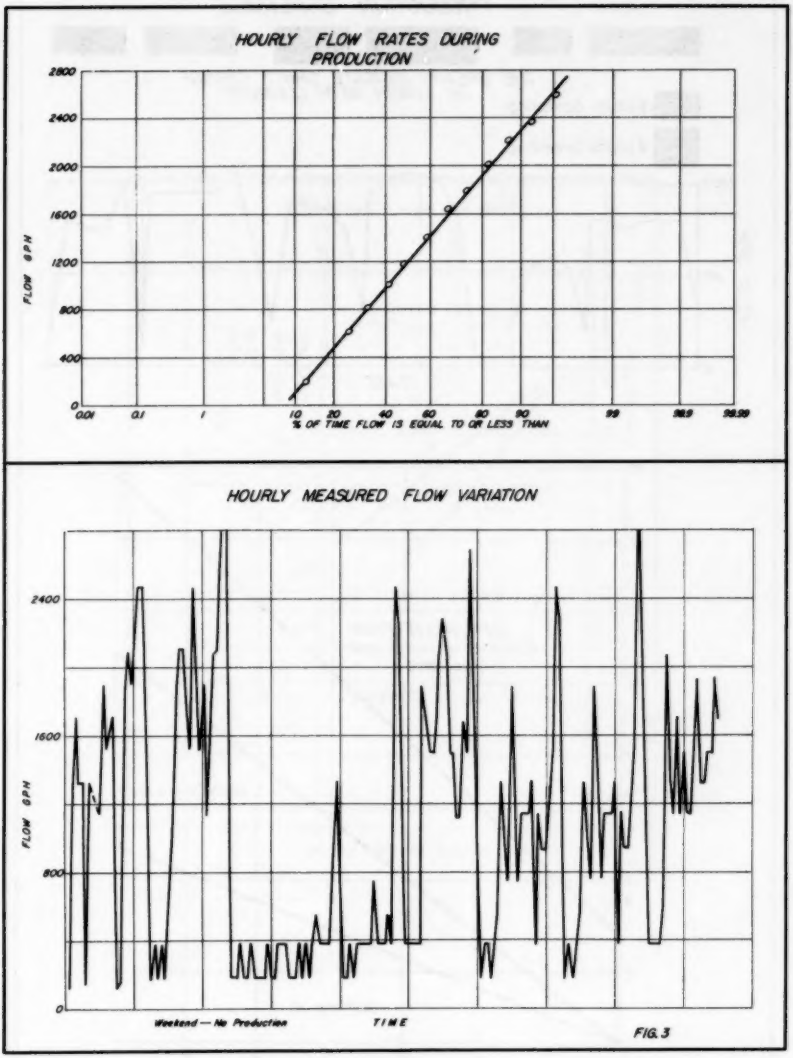
HOURLY FLOW RATES DURING PRODUCTION
FLOW GPH
2800
2400
2000
1600
1200
800
400
0
0.01
0.1
1
10
20
40
60
80
90
99
99.9
99.99
% OF TIME FLOW IS EQUAL TO OR LESS THAN
HOURLY MEASURED FLOW VARIATION
FLOW GPH
2400
1600
800
0
Weekend — No Production
TIME

FIG. 3

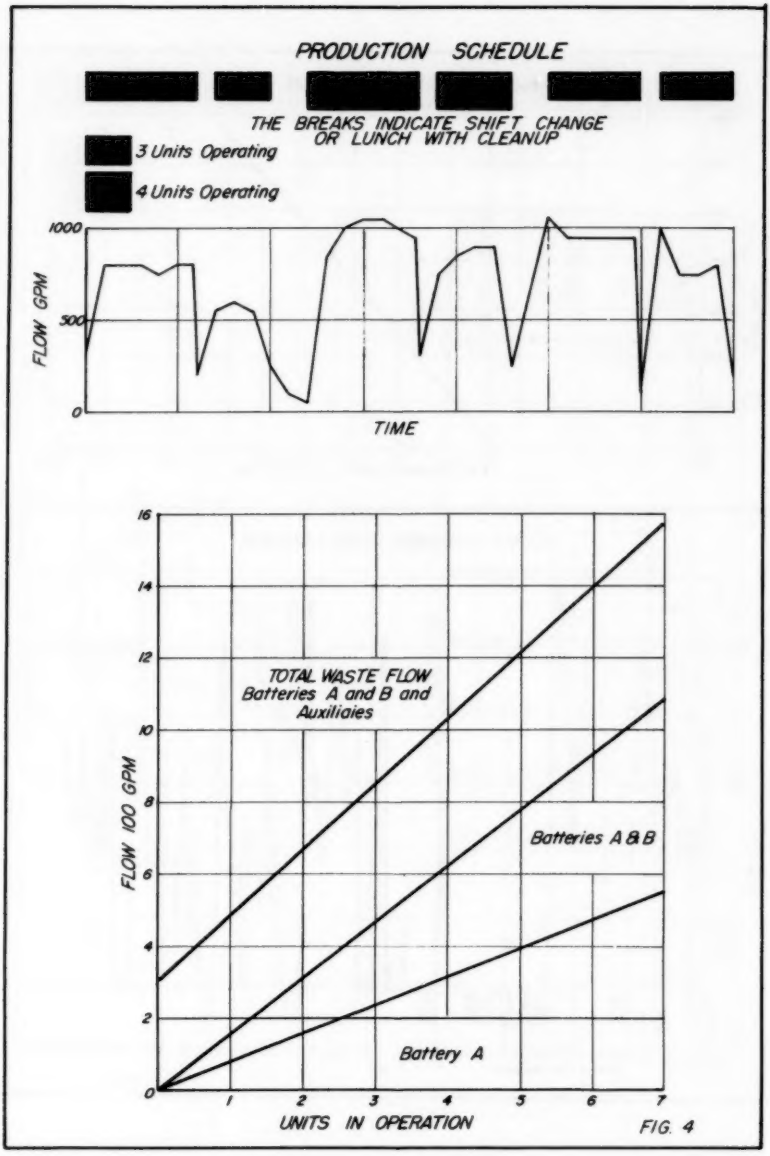
PRODUCTION SCHEDULE
THE BREAKS INDICATE SHIFT CHANGE OR LUNCH WITH CLEANUP
3 Units Operating
4 Units Operating
1000
500
0
FLOW GPM
TIME
16
14
12
10
8
6
4
2
0
FLOW 100 GPM
TOTAL WASTE FLOW Batteries A and B and Auxiliaies
Batteries A & B
Battery A
1
2
3
4
5
6
7
UNITS IN OPERATION

FIG. 4

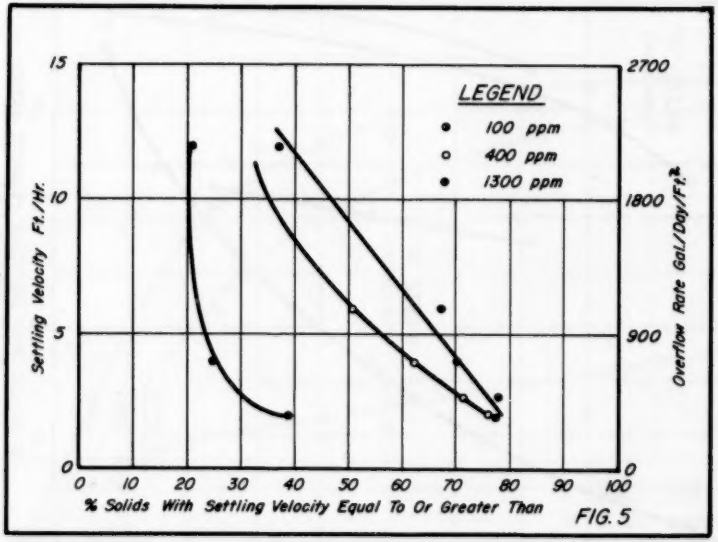
LEGEND
100 ppm
400 ppm
1300 ppm
Settling Velocity Ft./Hr.
Overflow Rate Gal./Day/Ft.²
15
10
5
0
2700
1800
900
0
0 10 20 30 40 50 60 70 80 90 100
% Solids With Settling Velocity Equal To Or Greater Than

FIG. 5

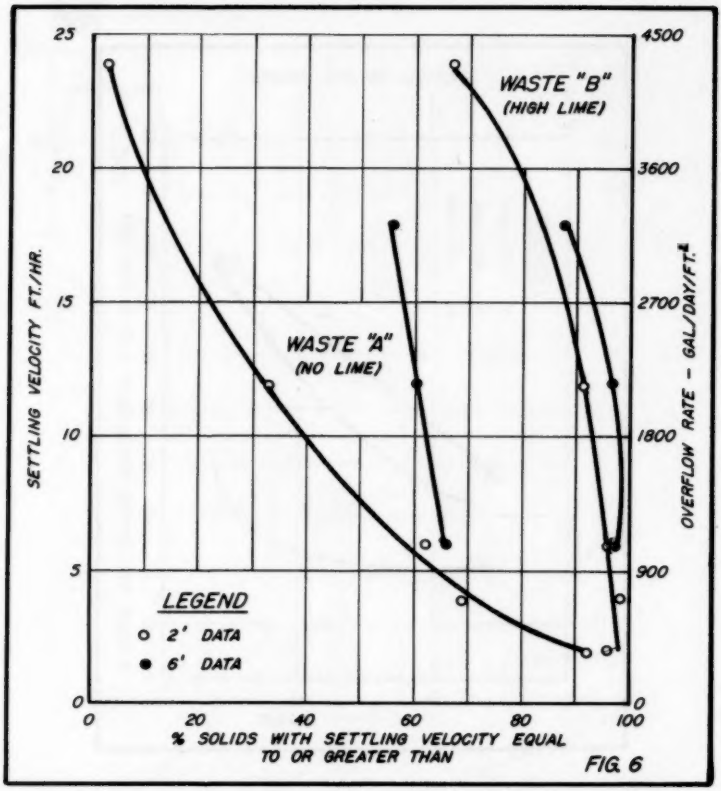
SETTLING VELOCITY FT./HR.
OVERFLOW RATE - GAL/DAY/FT.²
WASTE "B"
(HIGH LIME)
WASTE "A"
(NO LIME)
LEGEND
2' DATA
6' DATA
% SOLIDS WITH SETTLING VELOCITY EQUAL TO OR GREATER THAN
0
5
10
15
20
25
900
1800
2700
3600
4500
20
40
60
80
100

FIG. 6

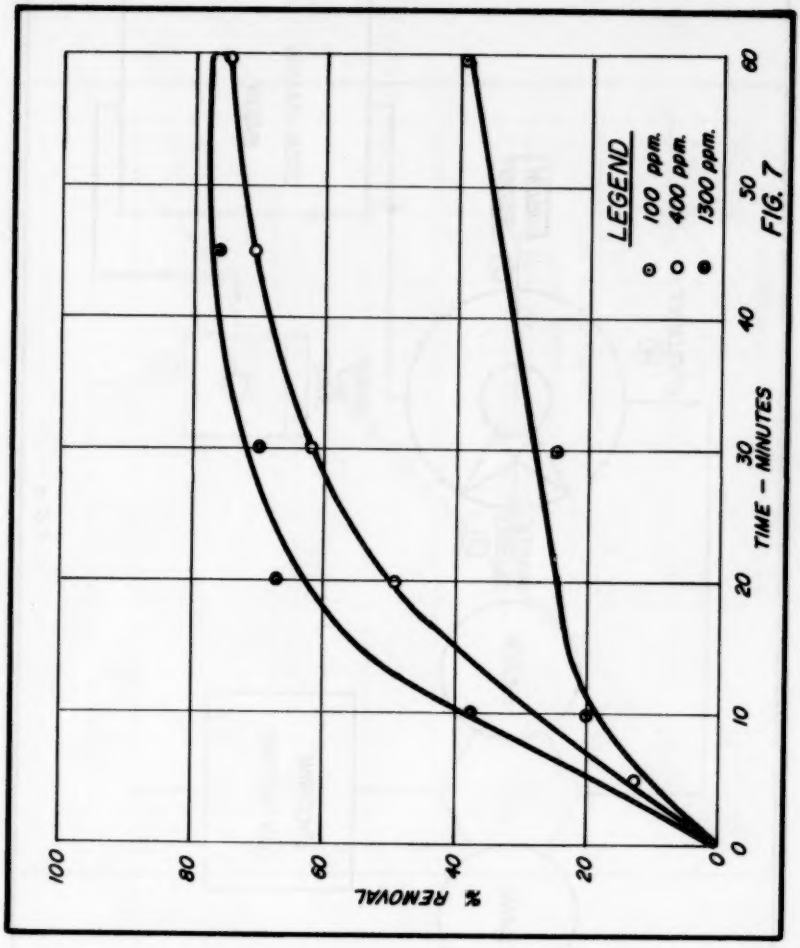
% REMOVAL
100
80
60
40
20
0
0
10
20
30
40
50
60
TIME - MINUTES
LEGEND
100 ppm.
400 ppm.
1300 ppm.

FIG. 7

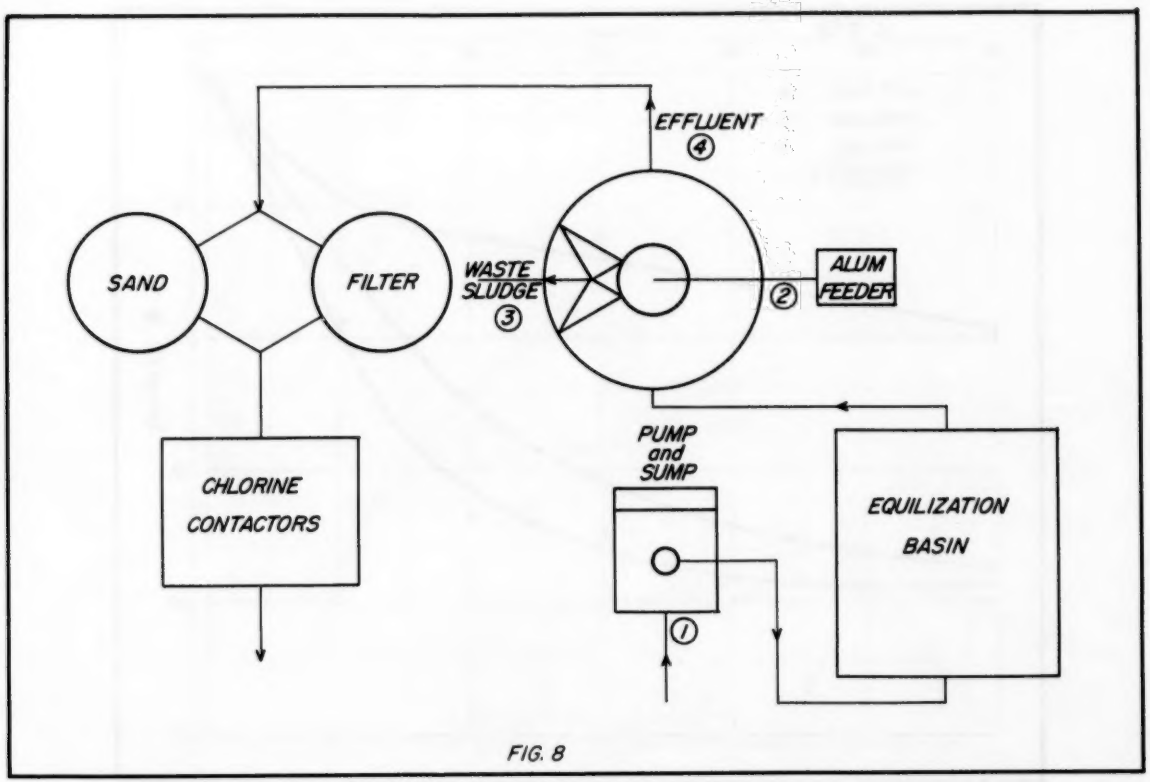
EFFLUENT
4
SAND
FILTER
WASTE
SLUDGE
3
2
ALUM
FEEDER
PUMP
and
SUMP
CHLORINE
CONTACTORS
EQUILIZATION
BASIN
1

FIG. 8

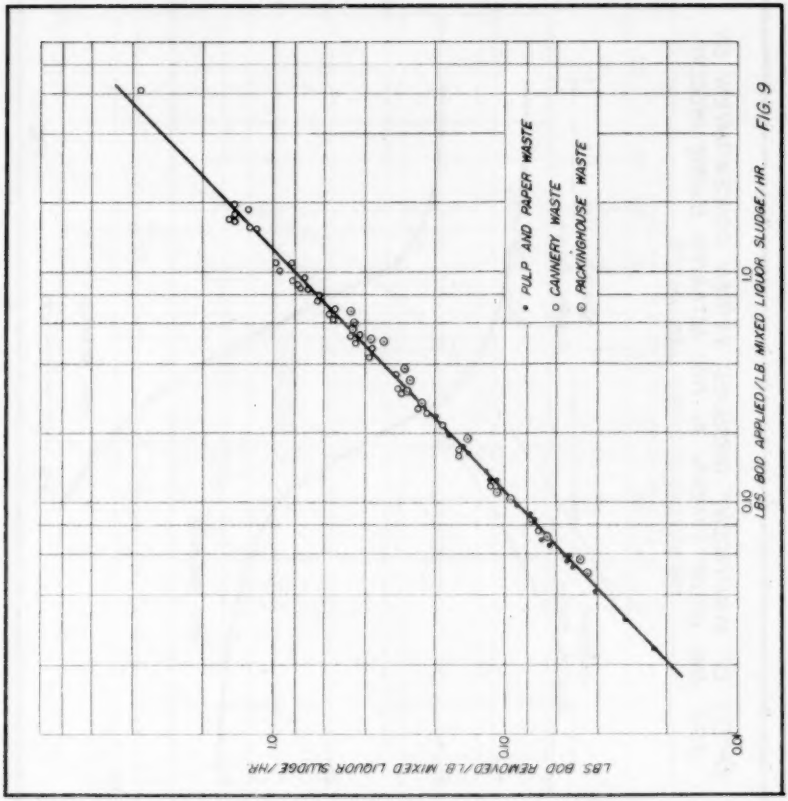
• PULP AND PAPER WASTE
○ CANNERY WASTE
⊙ PACKINGHOUSE WASTE
LBS. BOD APPLIED/LB. MIXED LIQUOR SLUDGE/HR.
LBS BOD REMOVED/LB MIXED LIQUOR SLUDGE/HR
1.0
0.10
0.01
0.10
1.0
0.01

FIG. 9

EFFECT OF INSUFFICIENT DISSOLVED OXYGEN CONCENTRATION ON BOD AND COLOR REMOVAL IN THE ACTIVATED SLUDGE PROCESS TREATMENT OF PULP AND PAPER

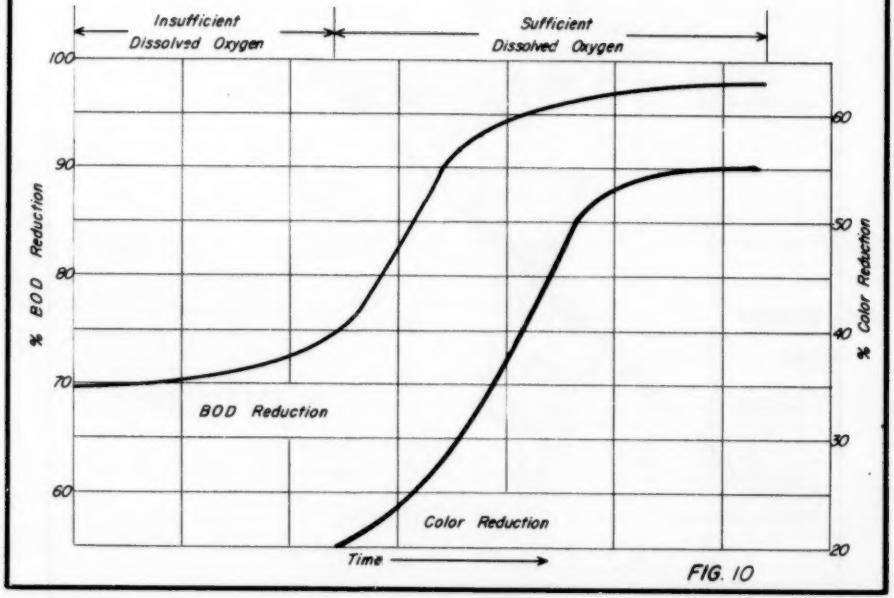

FIG. 10

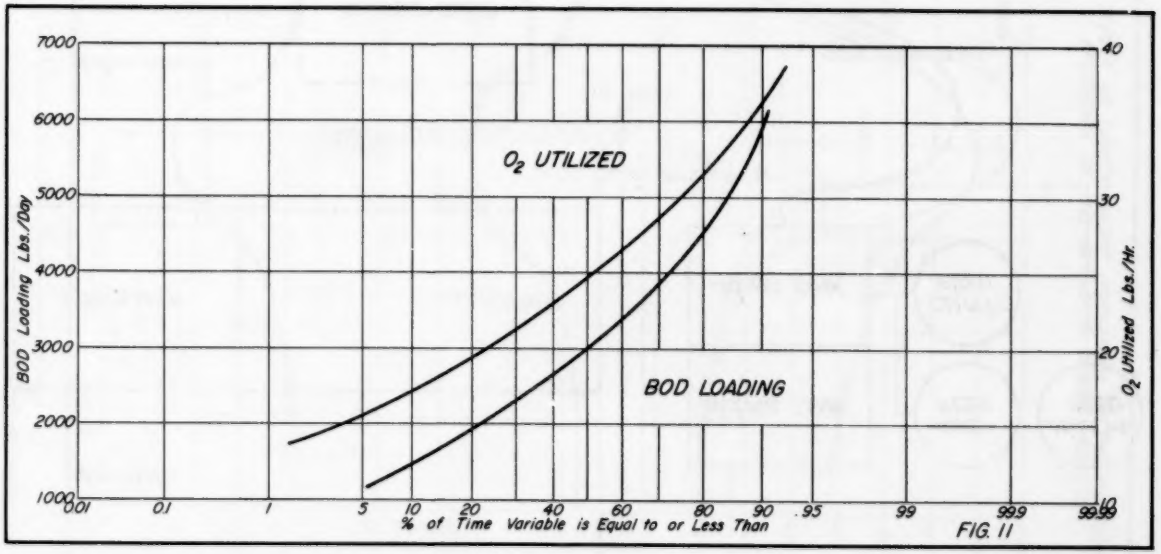
7000
6000
5000
4000
3000
2000
1000
BOD Loading Lbs./Day
40
30
20
10
O2 Utilized Lbs./Hr.
O2 UTILIZED
BOD LOADING
.001
.01
.1
1
5
10
20
40
60
80
90
.95
99
99.9
99.99
% of Time Variable is Equal to or Less Than

FIG. 11

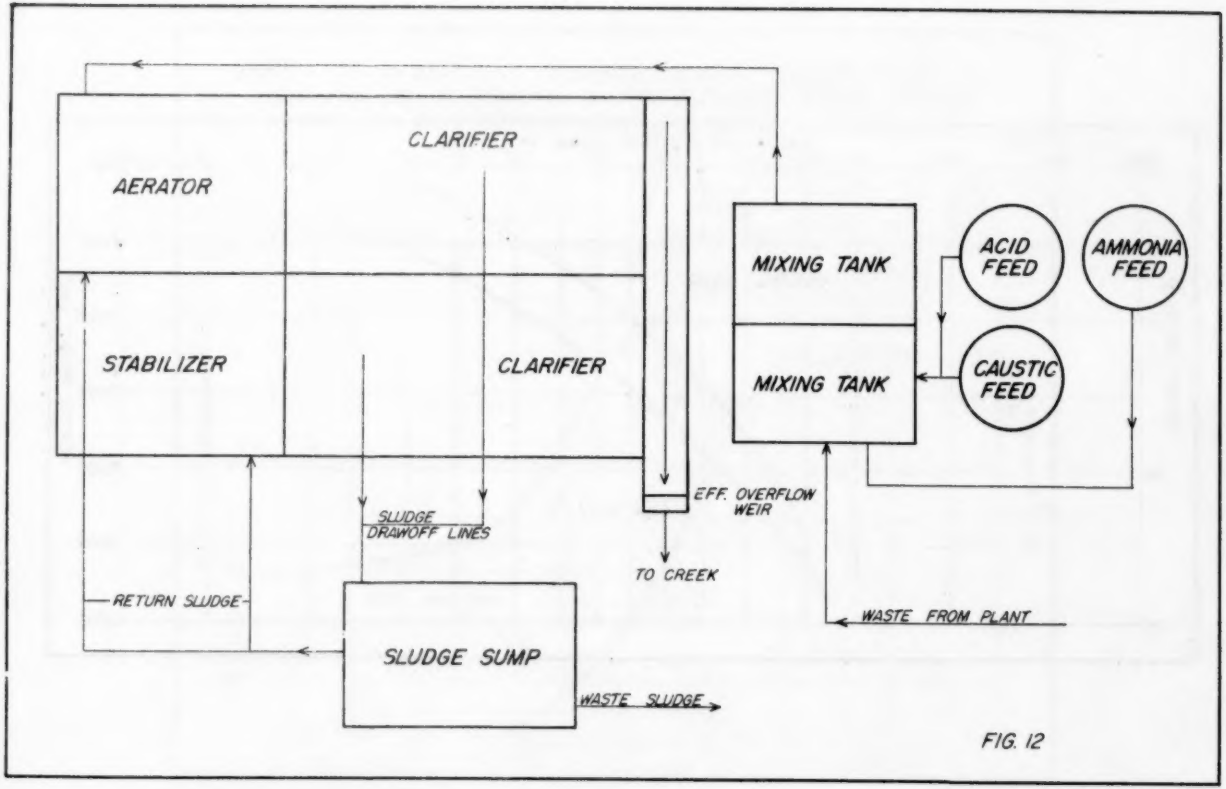
AERATOR
CLARIFIER
STABILIZER
CLARIFIER
MIXING TANK
MIXING TANK
ACID FEED
AMMONIA FEED
CAUSTIC FEED
EFF. OVERFLOW WEIR
TO CREEK
SLUDGE DRAWOFF LINES
RETURN SLUDGE
SLUDGE SUMP
WASTE SLUDGE
WASTE FROM PLANT

FIG. 12

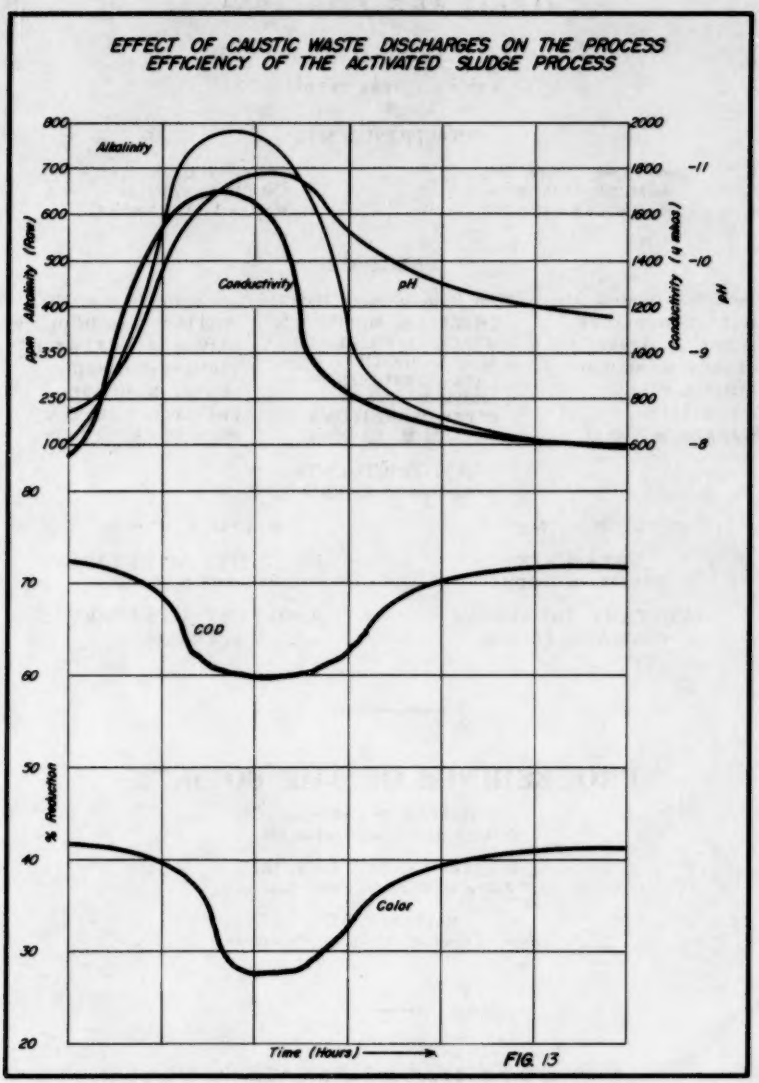
EFFECT OF CAUSTIC WASTE DISCHARGES ON THE PROCESS EFFICIENCY OF THE ACTIVATED SLUDGE PROCESS
Alkalinity
Conductivity
pH
COD
Color
ppm Alkalinity (Raw)
Conductivity (μ mhos)
pH
% Reduction
Time (Hours)
800
700
600
500
400
350
250
100
2000
1800
1600
1400
1200
1000
800
600
-11
-10
-9
-8
80
70
60
50
40
30
20

FIG. 13

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